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MINIMIZATION OF STREAK CAMERA ERRORS IN DETONATION  
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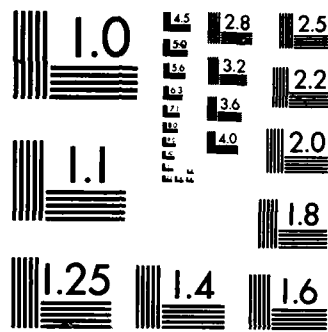
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# Minimization of Streak Camera Errors in Detonation Studies

by  
H. Dean Mallory  
*Research Department*

AUGUST 1986

NAVAL WEAPONS CENTER  
CHINA LAKE, CA 93555-6001



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# Naval Weapons Center

## FOREWORD

The work described in this report was performed in fiscal year 1986 under NWC Project No. 138090, Independent Research. The work derives and shows application of equations of importance to all phases of streak camera work. In particular, formula are given which can maximize data yield.

This report was reviewed for technical accuracy by Dr. D. C. Lind.

Approved by  
R. L. DERR  
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19 ABSTRACT (Continue on reverse if necessary and identify by block number) It is common knowledge in the detonation community that streak camera velocity traces should be near 45 degrees for best results. Yet, there seems to be no systematic explanation for that belief. In this report some derivations are presented to show that such belief is indeed grounded in fact. The Naval Weapons Center is particularly interested in the Los Alamos Wedge Test. This test has in fact shown itself to be important in understanding the complex phenomenon of sensitivity. The derivations presented are applicable to that test to record the time at which a building detonation wave undergoes the transition to its steady-state velocity.				
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It is common knowledge in the detonation community that streak camera velocity traces should be near 45 degrees for best results. Yet, there seems to be no systematic explanation for that belief. In this report some derivations are presented to show that such belief is indeed grounded in fact. The Naval Weapons Center is particularly interested in the Los Alamos Wedge Test (which was first presented as an engineering test<sup>1</sup>). This test has in fact shown itself to be important in understanding the complex phenomenon of sensitivity. The derivations presented are applicable to that test to record the time at which a building detonation wave undergoes the transition to its steady-state velocity.

Edels and Whittaker<sup>2</sup>, in a paper detailing the theory of practical design of modern streak cameras, discussed various types of errors such as those that occur due to different placements of the rotating mirror axis. Some other errors discussed were those that can occur during the reading of a record. It is errors of the latter type that we will be concerned within this report.

A phenomenon moving with either a constant or variable velocity will trace out a path in the focal plane of the camera such that the tangent to the path is given by

$$\tan \alpha = \frac{Mv}{V} \quad (1)$$

where  $M$  is camera magnification,  $V$  is camera writing rate, and  $v$  is the velocity of the phenomenon under observation, such as a detonation. Assuming the camera has been properly brought up to speed so that  $V$  is constant, if  $v$  is also constant, then a path inclined at angle  $\alpha$  to the time axis will be recorded. Accuracy in the determination of  $v$  can only be influenced by errors in the determination of  $M$ ,  $V$ , and  $\alpha$ . Edels and Whittaker were primarily concerned with errors in  $\alpha$  since only these were attributable to camera design.

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<sup>1</sup>J. B. Ramsay and A. Popolato. "Analysis of Shock Wave and Initiation Data for Solid Explosives," presented at Fourth Symposium (International) on Detonation, Office of Naval Research, ACR-126, October 1965, pp. 233-238.

<sup>2</sup>H. Edels and D. Whittaker. "The Theory and Design of Rotating Mirror Cameras," *J. Sci. Instr.*, Vol. 32, 1955, pp. 103-107.

From Equation 1, the fractional error in  $v$  due to an error in  $\alpha$  is

$$\frac{dv}{v} = \frac{2d\alpha}{\sin 2\alpha} \quad (2)$$

where it can be seen that Equation 2 is a minimum when  $\alpha = 45$  degrees. Edels and Whittaker further decomposed  $d\alpha$  into separate terms:

$$d\alpha = d\alpha_1 + d\alpha_2 + d\alpha_3$$

where these separate terms are record-reading errors associated with (a) photographic response of the film to produce a leading edge of the trace that can be located with a comparator, (b) sharpness of the trace (involves the circle of confusion and defocusing) that serves to limit the maximum error in the position of the leading edge, and (c) the error in the angle between the record trace and the time axis.

In any case, the errors can be treated in lumped form as in Equation 2. In this report Equation 2 has been extended to show that a velocity aberration is maximally visible at the same optimum 45-degree angle. The arguments leading to that proof can also be used to show that by proper selection of magnification and camera writing rate, maximum resolution of a different type of record can be achieved; in the latter category the LASL wedge for the determination of run to detonation can be included.

Figure 1 is a schematic streak record of a detonating explosive.

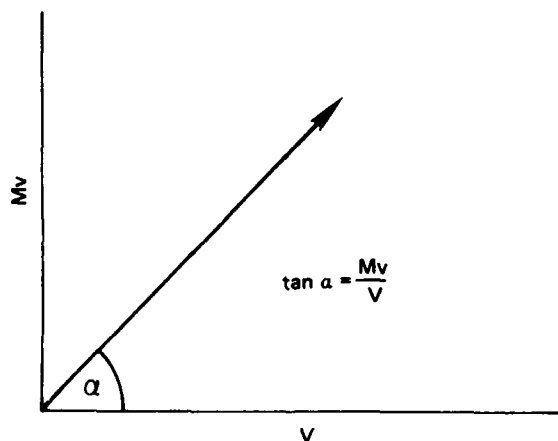


FIGURE 1. Schematic Detonation Trace.

Suppose we wish to observe a small perturbation in the detonation velocity. What record angle must be used to obtain maximum likelihood of detection? The quantity  $d\alpha/dv$  is normally constant; however, a nominal  $\alpha$  can be fixed over wide values by choice of  $M$  or  $V$ . We are required to

know the angle  $\alpha$  where  $d(da/dv)$  is a maximum; this is to say that the curve of  $(d/da)(da/dv)$  versus  $\alpha$  is a maximum at optimum  $\alpha$ . We are therefore concerned with an equation

$$f(\alpha'', \alpha) = 0$$

where

$$\alpha'' = \frac{d}{d\alpha} \left( \frac{d\alpha}{dv} \right)$$

For a maximum or minimum, the first derivative of the dependent variable  $\alpha$  is zero

$$\frac{d\alpha}{d\alpha}'' = - \frac{2M}{V} (\cos^2 \alpha - \sin^2 \alpha) = 0$$

so that  $\alpha = 45$  degrees. This angle determines a maximum value since  $(d/da)(da''/da)$  is negative. As a variant of this basic experiment, suppose a plane shock wave impacts a wedge and the wedge hypotenuse is silvered or polished so that shock arrival is observed by a reflectance change on the surface of emergence (Figure 2). The film record will be a before, but in this case

$$\tan \alpha = \frac{Mv \csc \theta}{V} \quad (3)$$

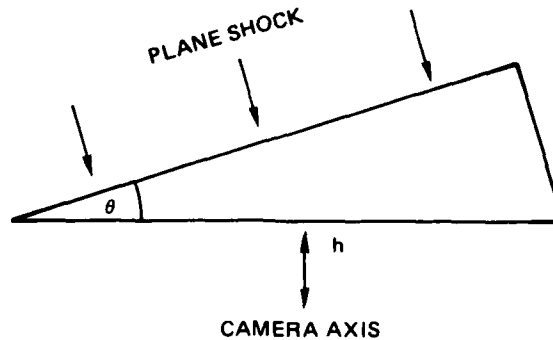


FIGURE 2. Shock Velocity Determination In a Wedge.

We wish to detect a perturbation in arrival along the side  $h$  and we must choose a wedge angle  $\theta$  to maximize the perturbation. In this case a maximum or minimum in change of slope is given by

$$\frac{d}{d\theta} \left( \frac{d\alpha}{dv} \right)$$



Let

$$x = \frac{Mv \csc \theta}{V}$$

then

$$\frac{d}{d\theta} \left( \frac{d\alpha}{dv} \right) = \frac{\frac{d}{d\theta} \left( \frac{dx}{dv} \right) - 2x \frac{d\alpha}{dv} \frac{dx}{d\theta}}{1 + x^2} = 0$$

which can be reduced to

$$\csc \theta = \pm \frac{V}{vM} \quad (4)$$

In our case only the positive value is significant. By first principles, the value of  $\theta$  in Equation 4 determines a maximum in the curve of the equation

$$f \left( \frac{d\alpha}{dv} \right) \theta = 0$$

Substitution of Equation 4 into Equation 3 again shows that  $\alpha = 45$  degrees. Wedge experiments are often arranged so that a plane detonation wave impacts the wedge at an angle. Practical considerations of the sound velocity in the wedge material place certain restrictions on the angle of impact to prevent the formation of a Mach stem. With the detonation velocity of the explosive fixed, the appropriate camera lens and writing rate can be determined from Equation 4.

Figure 3 shows the variation in  $(d/d\alpha)(d\alpha/dv)$ , plotted as percent change, as  $\alpha$  assumes different values. As can be seen from Figure 3, record angles that deviate from the 45-degree optimum can degrade camera performance.

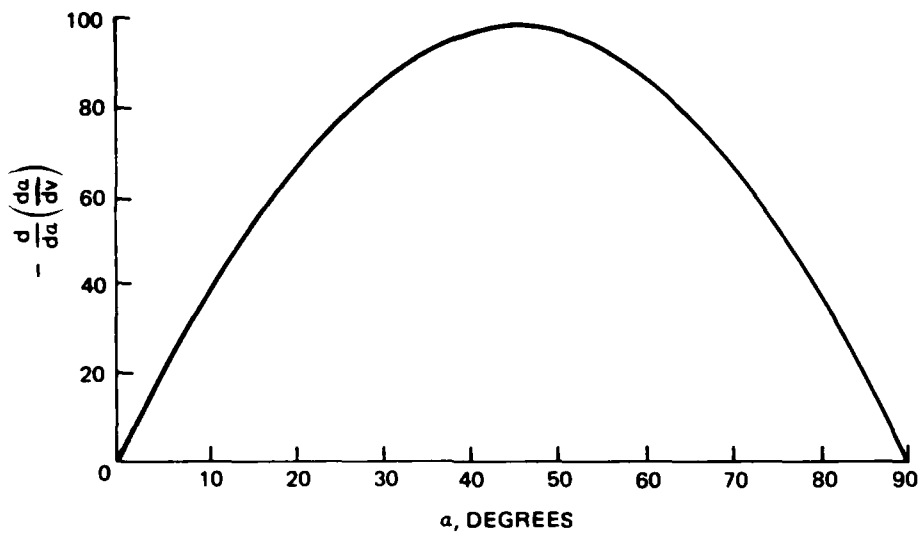


FIGURE 3. Variation  $\frac{d}{d\alpha} \left( \frac{d\alpha}{dv} \right)$  as a Function of Record Angle  $\alpha$ .  
Maximum sensitivity to change is at  $\alpha = 45$  degrees.

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